Stature estimation from calcaneal measurements in Thai

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Abstract

Stature estimation is an important method in forensic science as well as age estimation or sex determination for human identification. Stature data can increase the probability and accuracy of body identification. It is also useful in cases in which bodies were torn apart by a mass disaster or severe criminal acts. This occurs more frequently nowadays, which reduces the chances of gathering a complete body. The purpose of this study is to develop appropriate regression equations that allow the calcaneus bone to be used for stature estimation in Thai population. The study was performed by measuring nine variables of the calcaneus bone identical to the measurement definition and method of Bidmos (2006), from known cadaver height skeleton remains. The mean age of the 106 members of the sample was 65 years old. The measured data were analyzed by sex. Six and five simple linear regressions were derived from males' and females' data, respectively. The linear regression equation derived from maximum length (MAXL) parameter gave the most accurate measure in both sexes; since it has the highest coefficient of determination (r^2) (male 42%, female 40%) and the lowest standard error of the estimate (SEE) (male 6.37, female 6.94). Moreover, the equation derived from multiple regressions by stepwise method in males (MAXL and body height of calcaneus) gave higher accuracy (r^2 = 49%, SEE = 6.03) than simple regression, but in female, only MAXL showed a significant value which was the same as simple regression. Comparing the equations that were obtained from this study with Bidmos's (2006), it indicated that the accuracy was low as shown in the lower correlation coefficient and higher SEE. It is accepted that the equation which was derived from the linear regression method has specificity to population; therefore, the equation obtained from the present study can be a better alternative method to estimate stature in the Thai population.

Key words: CALCANEUS / LINEAR REGRESSION / STATURE ESTIMATION / THAI POPULATION

Introduction

There are many factors concerning the identification of unknown remains in forensic cases. Determination of race, sex, age, and stature based on human skeletal remains are common in forensic practices.

Stature determination can closely reflect the ante-mortem physique. There are two popular methods to determine stature: the Anatomical method and the Mathematical method. The Anatomical method, introduced by Dwight (1894) and slightly developed by Fully in 1956 (Raxter et al., 2006), determines living stature using the length of many bones in the body, together with correction factors and adjusting with depreciation pattern of stature on ages to attain a final estimation of living stature (Bidmos & Asala, 2005). This method is highly accurate, but it is time consuming to attain measurements for many bones in the body before calculation (Bidmos, 2006). Moreover, forensic cases usually involve incomplete sets of skeletal remain.

The Mathematical method was introduced and could determine stature from just one or a few pieces of bone. Commonly used bones presented high accuracy in stature determination by this method is the long bones found in the upper

and lower extremities. Due to the increasing cases of dismemberment resulting from violent crimes and natural disasters, it is necessary to develop regression equations from fragments of long bones (Bidmos, 2008; Chibba & Bidmos, 2007), and others to determine stature such as skull (Kalia, Shetty, Patil, & Mahima, 2008; Ryan & Bidmos, 2007), vertebra column (Nagesh & Kumar, 2006), metacarpal, metatarsal (Bidmos, 2008a; Cordeiro et al., 2009), talus and calcaneus (Bidmos, 2006; Bidmos & Asala, 2005; Zhang et al., 2009).

Foot is a favorite bone for statue approximation. Studies in the Indian population stature using foot dimension show significant relationship and accurate in North Indian (Kanchan et al., 2010a, 2010b) and the indigenous populations of North Bengal (Sen & Ghosh, 2008). The result of Sen & Ghoosh (2008) suggested that foot length gave more correlation coefficient than foot breadth in both male and female.

Determination of stature using calcaneus, the biggest and strongest foot bone with great potentials to be preserved compared to long bone, was introduced. The studies in South African Black and South Africans of European descent found that the determination of stature by using dimension of calcaneus has the standard error of the estimate (SEE) of only 4.2-5.4 cm (Bidmos, 2006; Bidmos & Asala, 2005) which is smaller than using dimensions of metacarpal (Karaman et al., 2009) or skull (Ryan & Bidmos, 2007). Therefore, the use of calcaneus to determine stature becomes more accurate.

There are a few stature studies in Thai population. Khanpetch estimated cadaver stature from long bone and demonstrated very high accuracy (89.3%) from ulna (SE 4.84-6.92) (Khanpetch et al., 2010). The most accurate mathematical stature estimates was obtained from the same population being examined and to create the equations (Bidmos, 2006; Bidmos & Asala, 2005; Cordeiro et al., 2009; Işcan, 2005). Because of the limitation of the application of regression and discriminant functional equations to the population group from which they have been derived, local data is the best in forensic context. Therefore, to apply this method to the Thai population specifically, we have to conduct a statistical study to collect Thai population's calcaneus and stature data to find out the Thai specific relation between them and derive a specific regression equations for Thais to improve the accuracy of the Thai stature determination.

Materials and Methods

Materials

One hundred and six (70 males and 36 females) Thai calcaneus bones (known as cadaveric height) whose documented age at death ranged from 26-94 years old (the mean for male and female = 65.29 years and 64.89 years, respectively) were obtained from the Department of Anatomy, Chiangmai University. The skeletons were collected from the years 2006-2009. The cadavers were donated from many parts of Thailand mostly from the north. The bones that present pathological conditions such as fracture with or without malunion, pin and plates, bad erosion or loss of bone density, were excluded for this study.

2.2. Methods

Nine parameters, Maximum length (MAXL), Cuboidal facet height (CFH), Load arm length (LAL), Body height (BH), Maximum height (MAXH), Middle breadth (MIDB), Dorsal articular facet length (DAFL), Dorsal articular facet breadth (DAFB), Minimum breadth (MINB), were measured followed the method of Bidmos (Bidmos, 2006) on each left calcaneus bone using vernier sliding caliper to the nearest 0.1 cm.

There was no significant difference between sides (Bidmos & Asala, 2005), the left calcaneus bone was used in the present study. If it was not available the right calcaneus bone was used instead. The data from males and females

were collected separately. The statistical methods used to analyze the data included: 1). Descriptive statistics were used to describe calcaneal measurement data such as means, standard deviations (SD), and variances. 2). Simple linear regression analysis which individual variables of the calcaneus was regressed against living stature from cadaver data to obtain regression equations. 3). Multiple linear regressions were performed by using the stepwise method to find the best multiple regression equation. From these results, the correlation coefficient (r), coefficient of determination (r^2) and standard error of the estimate (SEE) were obtained. All data were analyzed by using a statistical package SPSS for Windows version 17.0. Statistical significance was considered at p-value < 0.01.

Results

Descriptive statistic of each calcaneal measurement

From 106 case samples, the average stature of male and female was 165.24 and 153.28 centimeters, respectively.

The mean and standard deviation (SD) of the calcaneal measurements are illustrated in Table 1. Mean values of all measurements of male were significantly higher than those of female at p-value < 0.01, as indicated by the independent sample t-test. The parameter showing the highest standard deviation was MAXL for both sexes. The second was MAXH for both sexes. The third was BH for male and LAL for female.

Variables	Male (n=70)		Female (n=36)		*t*-value	*p*-value
	Mean	SD	Mean	SD		
MAXL	7.99	0.49	7.34	0.36	6.964**	0.000
CFH	2.66	0.16	2.35	0.19	8.868**	0.000
LAL	4.81	0.28	4.39	0.30	7.125**	0.000
BH	3.76	0.30	3.30	0.23	8.065**	0.000
MAXH	4.41	0.31	3.91	0.34	7.673**	0.000
MIDB	4.18	0.24	3.73	0.18	10.027**	0.000
DAFL	2.88	0.24	2.57	0.25	6.27**	0.000
DAFB	2.47	0.20	2.24	0.30	4.687**	0.000
MINB	2.47	0.24	2.09	0.20	8.084**	0.000

Table 1. Descriptive statistic of each calcaneal measurement, t-value and p-value

** Significant at p < 0.01.

Simple linear regression analysis

In the male group, six of the nine parameters had significantly positive correlation with cadaver height. MAXL shows the highest correlation of 0.65 and the least SEE is 6.37. The other variables are listed in descending order of correlation as shown in Table 2. Dorsal DAFL, MINB, and DAFB are not significantly correlated with cadaver height. The r^2 values of the significant variables are between 14% - 42%; the highest value is MAXL.

In the female group, five of the nine measured variables display significantly positive correlation with cadaver height. MAXL showed the highest correlation coefficients of 0.63 (Table 3) which is the same value as of males. The other variables are listed in descending order of correlation coefficient.

Multiple regression analysis

By using stepwise method, the best equation for male stature estimation is the MAXL and BH of calcaneus (Table 4). In comparison to simple linear regression equation, the multiple linear regression equation produced higher correlation coefficient (r = 0.70) and coefficient of determination (r^2 = 49%). In the female group, the best equation is derived from MAXL which in agree with simple linear regression.

Male equations (n=70)	Correlation	r^2	*p*-value	SEE
78.588+(10.847×MAXL)	0.65**	42%	0.000	6.37
81.772+(17.362×LAL)	0.59**	34%	0.000	6.75
112.286+(14.094×BH)	0.51**	26%	0.000	7.16
112.016+(12.07×MAXH)	0.45**	20%	0.000	7.44
114.119+(19.22×CFH)	0.37**	14%	0.002	7.75
111.745+(12.788×MIDB)	0.37**	14%	0.002	7.75
134.74+(10.59×DAFL)	0.30	9%	0.011	7.94
141.995+(9.411×MINB)	0.28	8%	0.020	8.01
162.993+(0.91×DAFB)	0.02	0%	0.853	8.33

Table 2. Fitted equations for stature estimation, correlation and standard error of estimation from each variable of male's calcaneus.

** Significant at $p < 0.01$

Female equations (n=36)	Correlation	r^2	*p*-value	SEE
41.08+(15.281×MAXL)	0.63**	40%	0.000	6.94
84.021+(21.015×BH)	0.55**	30%	0.000	7.46
103.224+(19.463×DAFL)	0.54**	30%	0.001	7.51
89.383+(14.562×LAL)	0.50**	25%	0.002	7.75
122.325+(13.827×DAFB)	0.47**	22%	0.004	7.88
115.528+(9.666×MAXH)	0.38	14%	0.024	8.29
96.145+(15.319×MIDB)	0.32	10%	0.059	8.48
133.34+(8.482×CFH)	0.18	3%	0.282	8.79
149.423+(1.846×MINB)	0.04	0%	0.807	8.94

Table 3. Fitted equations for stature estimation, correlation and standard error of estimate from each variable of female's calcaneus.

** Significant at $p < 0.01$

Fitted equations	Correlation	r^2	*p*-value	SEE
Male (n=70)				
65.165+8.769×MAXL)+7.992×BH)	0.70**	49%	0.000	6.03
Female (n=36)				
41.08+(15.281×MAXL)	0.63**	40%	0.000	6.94

Table 4. Fitted equations for stature estimation, correlation and standard error of estimation from multiple variables of the calcaneus of males and females

** Significant at $p < 0.01$

Comparison of the present study with others

The results of correlation coefficients (r) and standard error of the estimate (SEE) are compared with other studies (Table 5). The r value was greater than the study of Bidmos and Asala (2005). They measured the calcaneus in the South African samples. When taking other variables into account, such as skull measurements (Ryan & Bidmos, 2007), the present study shows greater correlation coefficient values.

Adversely, when compared to calcaneus measurements in South African descent (Bidmos, 2006) and metatarsal (Cordeiro et al., 2009), the present study shows lower values of r and the range of SEE was the highest.

Researcher	Variable	Range of r	Range of SEE
Bidmos & Asala (2005)	calcaneus	0.40 - 0.54	4.0-5.9
Bidmos (2006)	calcaneus	0.45 - 0.81	4.2-5.4
Cardeiro (2009)	metatarsal	0.61 - 0.79	4.3-5.7
Ryan & Bidmos (2007)	skull	0.40 - 0.54	4.4-6.2
Boonma et al. (2010)	calcaneus	0.37 - 0.70	6.0-7.9

Table 5. Comparison of correlation coefficient (r) and standard error of estimation (SEE) in the present study and previous studies.

Discussion

Determination of general demographic characteristics is the first step when confronted with unknown human skeleton identification cases. Characteristics such as age, sex, race and stature can assist to determine the boundary of possible features and provide greater chances for identification. It was reported that foot dimensions could estimate the human height especially based on the foot length (Agnihotri et al., 2009; Kanchan et al., 2008; Sen & Ghosh, 2008). The calcaneus bones were used to determine sex (Bidmos & Asala, 2003; Kumar et al., 2009; Zhang et al., 2008) which supported the present study. All nine parameters of calcaneal measurements of males were higher than females. Moreover, calcaneus bone was highly related to foot length. Therefore, calcaneus can be used to estimate a person's height. From Bidmos' study, nine parameters of calcaneus were measured in both South African blacks (Bidmos & Asala, 2005) and South African of European descent (Bidmos, 2006).

Many parameters of calcaneus can provide highly accurate stature estimation. The accuracy of regression model was measured by the value of SEE and r^2. Low SEE and high r^2 indicated high accuracy. In the present study r^2 value is low to moderate level (14%-49%) and SEE lengths (6.0-7.9) is wider than that of Bidmos' study (4.0-5.9) and MAXL parameter gives the most accurate in both sexes as well as in Bidmos' study. When compared to others studies (Table 5), the correlation coefficient within an average range level but SEE remains the highest.

There were only two published articles in Thai by Sangvichien (1985) and Khanpetch (2010), both studied in long bones. Sangvichien presented seven regression equations for each sex with SEE (2.1-5.3). Although the SEE was very low, but small sample size (50 males and 27 females), hence both the left and right side of each subject were used. Khanpetch's study showed higher r^2 (80.2% - 89.3%) and SEE (4.8-6.9) than those of Sangvichien. Although the stature estimation accuracy from calcaneus is lower than long bone but the correlation coefficient of maximum length equation and multiple regression equations are in the acceptable range (0.63-0.70).

The limitation of the present study was the small sample size due to missing calcaneus, badly erosion and many osteophytes in the donated skeletons from the elderly. In addition, there are more male skeletons collected compared to female's which could contribute to a more accurate regression equation derived from males than females.

Due to a stature secular trend is increasing (Chen & Ji, 2009), it is important to revise the linear regression equation continuously in future study. Violent crime and mass disaster cause more incomplete skeletons, regression equation should be derived from different parts of the human body. Furthermore, increase number of female sample might help to increase accuracy in the stature estimation.

Conclusion

The present study shows that calcaneus can be used to estimate stature among Thai. The regression formulae for stature estimation from individual and combination variables of the calcaneus were derived based on cadaver height. The correlation coefficients obtained from the maximum length equation and multiple linear regression equations were between 0.63 and 0.70 indicating a moderate correlation between cadaver height and calcaneal measurements. For stature estimation, the range of the SEE (6.0 - 7.9) from the present study is high when compare to that obtained from intact long bones. However, if only fragments of long bone or bones of the hands and feet are available, the calcaneus is useful for stature estimation. The maximum length (MAXL) of the calcaneus is the most useful parameter for stature estimation.

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