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Stature estimation from long bone lengths in a Thai population

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ABSTRACT

The estimation of stature is a very important step in developing a biological profile for forensic identification. However, little previous work has been done on stature estimation among modern Thai people, despite a growing number of forensic cases in Thailand in recent years. The current study was carried out on a sample of 200 skeletons from a northern Thai population (132 males and 68 females), ranging in age from 19 to 94 years. The maximum lengths of six long bones (humerus, radius, ulna, femur, tibia and fibula) were measured and stature reconstruction formulae generated using linear regression. These equations were then tested on a holdout sample of 15 females and 15 males. Results reveal that the three lower limb bones are the most accurate estimators of stature among the males, with the fibula equation producing the lowest standard error of the estimate (SE = 4.89 cm), followed by the femur (SE = 5.06 cm). Results for females were mixed. The femur produced the lowest standard error among the females (SE = 5.21 cm), followed by the radius (SE = 5.63 cm). However, when tested against the holdout sample ($n = 30$), the femur equations were considerably more accurate, with a mean absolute error of 3.5 cm and a median absolute error of 2.4 cm. Females exhibited a higher standard error of the estimate than reported in many previous studies. This higher error may be the result of a recent secular trend in stature affecting the females of our sample somewhat more than the males.

1. Introduction

Stature is often an important piece of information when creating a biological profile for personal identification in a forensic context, and it may provide a particularly valuable clue about an unknown individual when the person is unusually tall or short for their population. However, populations vary in terms of the relationship between limb bone lengths and stature, and stature equations have been shown by many researchers to perform less well when developed on one population and applied to another (e.g. [1–3]). Therefore, unique stature estimation equations may be required for each population of interest.

Many stature studies focus on a limited set of long bones for stature estimation (e.g. [1,3–6]), while a few have focused on all six major bones of the arms and legs [2,7–11]. Early work by Trotter and Gleser [2] on Americans who died in the first half of the 20th Century suggested that the long bones of the lower limb provide the most accurate stature estimates, as measured by the standard error of the estimate, and later studies among various populations worldwide have confirmed this observation [1,7–9,11,12]. Among several of these studies that considered bones of both the upper and lower limbs, and used minimum sample sizes of 50 individuals for each regression equation, ranges of the standard errors of the estimate for males are: femur (1.6–4.7 cm), tibia (1.9–4.6 cm), fibula (2.0–4.4 cm), humerus (2.7–5.1 cm), radius (3.0–5.1 cm), and ulna (3.1–5.0 cm) [1,2,8–10]. For females, ranges are: femur (1.7–3.8), tibia (2.2–3.8 cm), fibula (2.2–3.8 cm), humerus (2.6–4.5 cm), radius (3.4–5.1 cm), and ulna (2.8–4.8 cm) [2,8,9]. However, differential preservation of limb bones is often a problem in forensic contexts, so development of stature equations from both the upper and lower limbs is preferred when time and resources permit.

The femur provides the most accurate equations for stature estimation in a majority of past studies (e.g. [2,7–9]), probably because it contributes most to living height. The femur is also less influenced by nutritional and other environmental stresses [13,14], as well as secular changes in body proportions [15], than the more distal bones of the limbs. Thus, the femur seems to have a more stable relationship to stature than the tibia, radius, or ulna even under changing environmental circumstances. Stature equations from the upper limb are almost universally less accurate at estimating adult height than those from the lower limb, but

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different populations vary in terms of whether the humerus or radius is the most accurate predictor in the arm [2,8,10–12].

Only limited work has been done on stature reconstruction for populations from Southeast Asia. Up until now, scientists in the Department of Forensics at Chiang Mai University in Thailand relied primarily on stature formulae developed on a northern Chinese sample [3] for their cases, presumably because Thai people have some genetic connections with China, both ancient and modern [16,17], and because the Chinese study was based on a reasonable sample size and included formulae for both the upper and lower limbs. However, stature estimation formulae were only generated for the males of Stevenson's [3] Chinese sample, limiting their utility, and the genetic relationship between Thai and Chinese populations has recently been confirmed to be stronger for southern China than for the north [16]. Furthermore, a recent test of these northern Chinese formulae conducted on 10 modern Thai males from the Chiang Mai area found that stature was overestimated 90% of the time. While overestimates from the femur averaged only about 2 cm in this test, those from the other limb bones ranged from 4 to 7 cm, indicating that the formulae are probably not adequate for use on modern Thai skeletons.

The only other relevant research on stature reconstruction for modern Thai people is a study published by Sangvichien et al. [18] on the lower limb bones of a mixed sample of 77 Thai and Chinese-Thai individuals. This study provided regression formulae for the three bones of the lower limb, but was based on a relatively small sample of females ($n = 27$), and an unknown mix of Thai and Chinese individuals who died more than 25 years ago. Furthermore, the resulting equations were never tested on a holdout sample to confirm their accuracy. Standard errors of the estimate for the females in this study were: femur (3.0 cm), tibia (4.6 cm), and fibula (4.4 cm). Standard errors for males were: femur (5.4 cm), tibia (5.1 cm), and fibula (4.2 cm). Results for both sexes are quite high compared to the ranges reported above for several previous studies on other populations.

The purpose of this study was to generate new stature estimation formulae for modern Thais using both the upper and lower limbs, and a relatively large skeletal sample. Accordingly, stature estimation formulae were generated for the humerus, radius, ulna, femur, tibia, and fibula, and the relative accuracy of each formula was compared. Stature reconstruction formulae were also calculated for situations in which the sex of the individual is uncertain, such as might occur when a single limb or disarticulated bone is recovered in a forensic context. We tested our formulae, as well as those of Sangvichien et al. [18] and Stevenson [3] on a holdout sample of 15 males and 15 females to examine the relative accuracy of these equations on modern Thai individuals from the Chiang Mai Area.

2. Materials and methods

Two hundred adult skeletons from a modern Thai population (132 males, 68 females) were obtained from the Chiang Mai University Skeletal Collection curated at the Department of Anatomy, Faculty of Medicine, Chiang Mai University, Thailand. The mean age for both sexes is 67 years – with a standard deviation of 13.2 years and a range of 19–94 years for males, and a standard deviation of 13.6 years and a range of 26–93 years for females. All of the individuals in this collection died within 200–300 km of Chiang Mai city between 2006 and 2008, and are Thai citizens born between 1913 and 1987. The skeletons were divided into two groups. One group was used to generate regression equations for stature estimation (117 males, 53 females), and the other was used to test the resulting equations for accuracy (15 females, 15 males). Analyses of the overall stature of the sample, as well as interbone correlations, were performed on the combined sample of 132 males and 68 females.

Stature for each skeleton was measured directly from the cadaver prior to processing by measuring the length of the body from the vertex of the head to the heel of the foot with the cadaver in a supine position. Measured stature was not corrected to approximate living stature at this point. A metal tape was used to take stature measurements to the nearest centimeter. Once the bones were macerated and allowed to dry, the following measurements were taken with an osteometric board from Paleo-Tech Concepts on each of the six long bones according to the standards presented by Moore-Jansen et al. [19]: maximum length of the humerus, radius, ulna, femur, and fibula, bicondylar length of the femur, and standard length of the tibia from the superior articular surface of the lateral condyle to the tip of the medial malleolus. Two less commonly taken measurements of the tibia were also made: maximum length of the tibia from the intercondylar eminences to the medial malleolus, and articular length, taken from the lateral condyle of the proximal articular surface of the tibia to the lateral edge of the distal articular surface, excluding the intercondylar eminences and medial malleolus. These less common measurements were taken in order to assess their relative utility for stature estimation, to develop equations for use by forensic scientists in Thailand who may not have an osteometric board that allows for easy measurement of the tibia without inclusion of the intercondylar eminences, and for cases in which both the intercondylar eminences and medial malleolus are damaged.

All measurements were taken to the nearest 0.1 cm by one of us (PK). Both sides were measured when available. Each long bone measurement was tested for normality using a Kolmogorov–Smirnov test at an alpha level of 0.05. Pearson's product–moment correlations were calculated between the various long bone dimensions in order to assess the degree of similarity among the linear relationships of these bones, and to determine whether side asymmetry was great enough to warrant creation of separate equations for both sides of the body. Correlations were also calculated between stature and age for each sex to assess whether a significant secular trend in stature change was evident in the sample. Age is a good proxy for years since birth in this sample because all individuals in the sample died over a period of only three years.

Based on the results of the asymmetry study, measurements were averaged when available for both sides. Otherwise, whichever measurement was available for either the left or right side was used to create the regression equations. Complete data for all six limb bones were available for 154 skeletons (47 females, 107 males). A small group of 23 skeletons (8 females, 15 males) had no measurable leg bones. The remaining 23 individuals were missing at least one measurement in the upper or lower limb due to osteoarthritis, trauma, or postmortem damage.

Regression equations were calculated using SPSS version 18.0. Regression equations were generated for each sex separately ($n = 117$ males, 53 females) and for a combined sex sample comprised of the same 53 females, together with 53 randomly selected males from among the 117 individuals in the male sample. The reported equations include a correction to estimate living stature, which was accomplished by subtracting 2.0 cm from the equation's constant. Most researchers argue for a reduction in cadaver lengths of 2.0 cm in order to best approximate living stature, although a few argue for a smaller reduction in males of 1.2–1.6 cm [2,20–24].

Tests of the regression equations from our sample as well as those from previous studies were conducted on the holdout sample of 15 males and 15 females. The holdout sample was randomly selected from among the 154 individuals with no missing measurements. Tests were performed by estimating the stature for each individual in the holdout sample and comparing it to the stature before dissection. For comparative purposes, the absolute value of the error for each estimate was taken and then mean and median absolute errors were calculated.

3. Results

Descriptive statistics for male and female stature are provided in Table 1, along with the values for two other comparative samples [3,18]. The reported heights are cadaver lengths, as described above, not living stature.

Descriptive statistics for male and female long bone measurements are provided in Tables 2a and 2b. All measurements were found to be normally distributed. Our results indicate that Thai males in the sample average 11.7 cm (7.6%) taller than Thai females, but with considerable overlap between the two distributions. For example, 54% of females are taller than the shortest male, and 84% of males are shorter than the tallest female. However, toward the center of the distribution there seems to be good separation between the sexes, with only 18% of females being 160 cm or taller, while only 17% of males are 160 cm or shorter.

3.1. Secular trend in stature

Pearson's correlations between age and stature suggest increasing height among females over time, with a less dramatic effect among males. Age was negatively correlated with height in both the male ($r = -0.136$, $p = 0.12$) and female ($r = -0.445$, $p < 0.001$) samples, but only the female trend was significant.