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Forensic Anthropology Population Data

Sex estimation from measurements of the calcaneus: Applications for personal identification in Thailand

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ABSTRACT

As a coastal region, Thailand has been significantly affected by climate change. The impacts of climate change in Thailand – temperature increase, rising sea levels, and violent flooding – are predicted to multiply in both frequency and intensity in the next few decades, which may cause an increase in mass disasters and fatalities in the region. The 2004 tsunami catastrophe in Thailand demonstrated the lack of forensic anthropology expertise and the lack of population specific methods in the region. The goal of this research is to derive population specific discriminant functions from the calcaneus for sexing unidentified skeletal remains from a contemporary Thai population. Nine variables of the calcaneus were measured from 232 individuals (116 males and 116 females) of the Chiang Mai skeletal collection with age ranges from 22 to 96 years. All nine calcanei variables were sexually dimorphic. Multivariate and univariate discriminant function analyses were completed. The multivariate analyses showed accuracy rates from 81.5% to 87.7% in males and 84.0% to 87.7% in females. The accuracy rates from the univariate analyses ranged from 71.6% to 84.0% in males and 67.9% to 85.2% in females. Comparisons to other populations were made and the results demonstrated the need for population specific discriminant functions. Overall, the cross-validation accuracies ranged from 73.4% to 94.3% with males identified correctly more often than females. This study demonstrates that the calcaneus is useful for sex estimation in the contemporary Thai population.

1. Introduction

Skeletonized human remains are commonly recovered within medico-legal contexts and mass disasters. The forensic anthropologist carefully examines the remains and assists with the human identification through the creation of a biological profile (i.e. estimation of sex, age at death, stature, and biological affinity). Research has shown the importance of including forensic anthropologists as a vital component of the interdisciplinary teams that aid in the examination of unknown human remains [1–3]. The 2004 tsunami catastrophe in Thailand highlighted the lack of forensic anthropology expertise in the country. In 2013, the Excellence in Osteology Research and Training Center (ORTC) at the Faculty of Medicine, Chiang Mai University, began a doctoral degree program that promotes forensic anthropology research specifically within Thailand. However, despite efforts to develop forensic anthropology in Thailand there are still a scarcity of trained specialists and population specific data for establishing biological profiles remain insufficient [1]. Major climate-induced weather events (i.e. tropical storms, sea level rising, and violent flooding) are predicted to increase in frequency and intensity in Thailand in the next decade, which may cause an increase in the number of mass disasters, and thus fatalities, in the region [4]. Therefore there is an urgent need for the development of population specific osteometric methodologies for Thai populations.

When identifying skeletonized remains, the estimation of sex is of primary significance, as the estimation of age at death and stature are sex dependent [5]. Discriminant function analysis is often used for sex estimation. The pelvis and skull have been cited as the most accurate methods of sex estimation [6–10]. In practice however, these bones are often recovered in fragmented states due to postmortem damage and taphonomic changes, rendering them

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unsuitable for sex estimation [5,11–12] Therefore, developing methods for sex estimation from preservationally favored and/or fragmentary bones is essential. The calcaneus is the largest bone of the foot and is often recovered in forensic and archaeological contexts. This is due to the increased strength and density of the bone's trabeculae and because it is often encased in shoes and/or socks which serve as protection for the bone from exposed to taphonomic events [13–15].

Past research has demonstrated high accuracy rates for sex estimation from the calcaneus, however, these studies have cited the methods to be population specific [5,13,16–21]. Currently, there are no discriminant functions available for the estimation of sex from the calcaneus for Thai populations. The aim of this research is to derive population specific discriminant functions from the calcaneus for sexing unidentified skeletal remains from a contemporary Thai population.

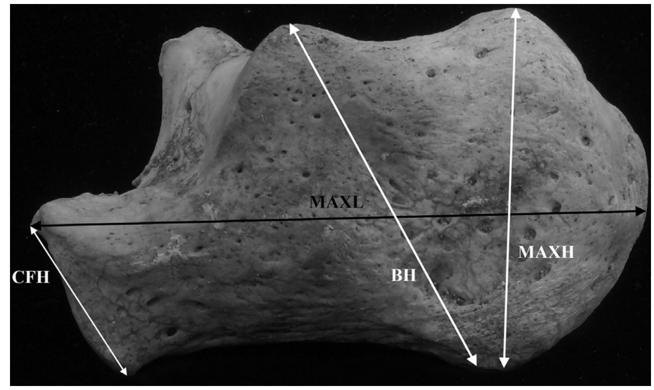

Fig. 1. Measurements of the calcaneus: maximum length (MAXL), maximum height (MAXH), cuboidal facet height (CFH), body height (BH).

2. Materials and methods

The present study examines the left calcanei of 232 individuals (116 males and 116 females) from the Chiang Mai skeletal collection housed in the Forensic Osteology Research Center (FORC) in the Faculty of Medicine at Chiang Mai University. The individuals utilized in this study ranged in age from 22 to 96 years old. The collection consists of 475 (291 males and 184 females) documented skeletons (i.e. sex, age at death, occupation, cause of death, birth dates, and death dates) who donated their bodies for educational purposes. The collection represents a contemporary Thai population as all of the individuals lived the majority of their life during the twentieth century; all individuals used in the present study were born between 1913 and 1989 and died between 2006 and 2014.

Two sample sets were randomly selected for this research. Sample 1 (original group) consisted of 81 male and 81 female calcanei. This sample was used in the derivation of discriminant function equations for the estimation of sex. Sample 2 (cross-validation group) is an independent sample, which consisted of 35 male and 35 female calcanei; none of the bones used for Sample 2 were used for Sample 1. Sample 2 was used to test the accuracy of the discriminant function equations derived using Sample 1.

Nine measurements were collected from each calcaneus following the protocol of Peckmann et al. [5]: maximum length (MAXL), maximum height (MAXH), cuboidal facet height (CFH), body height (BH), minimum breadth (MINB), load arm length (LAL), middle breadth (MIDB), dorsal articular facet breadth (DAFB), and dorsal articular facet length (DAFL). These variables are defined in Table 1 and shown in Figs. 1 and 2. All measurements were collected by one observer using a standard Vernier digital caliper and recorded to the nearest 1/100 of a millimeter (0.01 mm). A comparison of the measurements taken from paired male and female calcanei showed no statistically significant side differences with $p > 0.005$ (Bonferroni adjustment). Therefore, only left calcanei were measured. In cases where the left calcaneus was absent or showed evidence of trauma, damage, or pathological changes, measurements were taken using the right calcaneus.

Imprecision refers to the variability of repeated measurements and is due to measurement differences observed through intra- and inter-observer error testing; the higher the variability of the repeated measurements, the lower the precision, which results in a higher degree of measurement error [22]. Intra- and inter-observer error rates were examined by re-measuring 60 randomly selected calcanei (30 males and 30 females) from Sample 1. These sample sizes are statistically viable as previous studies have shown that a subsample of 10–20% of the total population should be used to test for intra-observer and inter-observer error [23]. For each measurement variable, the test statistic (t-value), the p-value, the technical error of measurements (TEM), the relative technical error of measurements (rTEM), and the coefficient of reliability (R) were calculated for both intra-and inter-observer error. The TEM evaluates measurement precision and provides an estimated standard deviation of the difference between two measurements [22]. The TEM is calculated using the following equation, where D is the difference in the first and second set of measurements (within one observer or between two observers) and where N is the total number of measurements examined [22]:

$$\mathrm{TEM} = \sqrt{\sum D^2/2N}$$

Table 1
Measurement descriptions.

Measurement	Description[a]
Maximum length (MAXL)	Maximum linear distance between the most anterior point of the calcaneus and the most posterior point of the calcaneal tuberosity
Maximum height (MAXH)	Maximum linear distance between the most superior point of the calcaneal tuberosity and the most inferior point of the calcaneal tuberosity
Cuboidal facet height (CFH)	Maximum linear distance between the most superior point of the cuboidal facet and the most inferior point of the cuboidal facet
Body height (BH)	Linear distance between the superior and inferior surfaces of the calcaneal body; taken at the midpoint between the most posterior point of the dorsal articular facet and the most anterior point of the calcaneal tuberosity, on the coronal plane
Minimum breadth (MINB)	Minimum distance between the medial surface of the calcaneal body, and lateral surface of the calcaneal body
Load arm length (LAL)	Maximum linear distance between the most anterior point of the calcaneus and the most posterior point of the dorsal articular facet
Middle breadth (MIDB)	Maximum linear distance between the most lateral point of the dorsal articular facet and the most medial point of the sustentaculum tali
Dorsal articular facet breadth (DAFB)	Maximum linear distance between the most medial point and the most lateral point of the dorsal articular facet
Dorsal articular facet length (DAFL)	Maximum linear distance between the most posterior point and the most anterior point of the dorsal articular facet

[a] Modified from Bidmos (2006).