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Forensic Anthropology Population Data

Bayesian modeling predicts age and sex are not required for accurate stature estimation from femoral length

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ABSTRACT

Despite the recognized flaws in applying traditional stature estimation equations such as those of Trotter and Gleser (1952) [5] to a contemporary population, there are currently no available alternatives for stature estimation in Australia that address these limitations. Post mortem computed tomography (PMCT) DICOM scans of the left and right femora were acquired from 76 Australian deceased individuals aged 17–76 years for metric analysis. Femoral bicondylar length, femoral epicondylar breadth and anterior–posterior (AP) diameter, medial-lateral (ML) diameter, circumference and cortical area at the femoral midshaft were measured on three-dimensional (3D) models to build statistical models for estimating stature. In addition, Australian individuals aged 16–63 years (n = 111) were measured in standing and supine positions to aid in the adjustment of supine stature of deceased individuals utilized in this study to standing stature. The results of this preliminary evaluation strongly indicate that the optimal model for estimating stature includes bicondylar femoral length and epicondylar breadth, that the effect of sex as an independent variable is very low, and there is limited practical benefit in including age in the estimation of stature. Our study indicates that the Australian population sampled represents a small yet significant shift in stature from the original Trotter and Gleser sample. Additionally, in the case of fragmentary remains, it was found that epicondylar breadth and AP diameter had the highest probability of accurate stature estimation in the absence of bicondylar femoral length. As stature forms a significant component of a biological profile and therefore aids in the personal identification of human remains, it is important that forensic anthropologists utilize the most accurate methodologies available. Stature estimation of Australian individuals is therefore achieved with higher accuracy through utilizing the femoral equations proposed in this study.

1. Introduction

Stature is an important measure of body size and is therefore a significant component when establishing a biological profile for the identification of human remains, particularly when discriminating individuals of the same sex and ancestry such as in the case of repatriation of service member remains. Stature can be estimated anatomically by measuring all skeletal elements that contribute directly to stature [1], or mathematically by using anthropometric measurements of body segments [2–4] or osteometric measurements of isolated long bones. Regression formulae utilizing measurements of long bones have the widest practical use as they can be applied to cases of incomplete human remains to estimate stature with high accuracy owing to the correlation between stature and limb bone dimensions. The Trotter and Gleser stature estimation equations [5,6] derived from an African American and European American population have become the most widely utilized in forensic anthropology, however more contemporary research has demonstrated the need for population-specific equations to increase the accuracy of stature estimation. As a result, a number of published studies have constructed population-specific stature regression equations using

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Table 1
Studies that have published population-specific stature regression equations using long bones [7–25].

Authors	Year	Population	Sample size	Bones utilized
Jeong and Meadows Jantz	2016	Korean	113	Femur, tibia, humerus, radius, lumbar vertebral column
Gocha et al.	2013	South-East Asian	64	Femur, tibia, fibula, humerus, ulna, radius, vertebral column
Giurazza et al.	2012	Italian	200	Femur, skull
Mahakkanukrauh et al.	2011	Thai	200	Femur, tibia, fibula, humerus, ulna, radius
Ross and Manneschi	2011	Chilean	276	Femur, tibia, humerus
Wilson et al.	2010	American	242	Femur, tibia, fibula, humerus, ulna, radius
Hasegawa et al.	2009	Japanese	434	Femur, tibia, humerus
Dayal et al.	2008	South African White	169	Femur, tibia, fibula, humerus, ulna, radius, lumbar vertebral column
Petrovečki et al.	2007	Croatian	43	Femur, tibia, fibula, humerus, ulna, radius
Duyar et al.	2006	Turkish	242	Tibia, ulna
Sarajlić et al.	2006	Bosnian	50	Femur, tibia, fibula
Hauser et al.	2005	Polish	91	Femur
Ross and Konigsberg	2002	Balkan	177	Femur, tibia, humerus
Radoinova et al.	2002	Bulgarian	416	Tibia, fibula, humerus
Munoz et al.	2001	Spanish	104	Femur, tibia, fibula, humerus, ulna, radius
Mall et al.	2001	Middle-European	143	Humerus, ulna, radius
De Mendonca	2000	Portuguese	200	Femur, humerus
Kahana et al.	1996	Israeli	91	Femur, humerus

long bone lengths (Table 1) [7–25]. Although many studies introduce contemporary equations, there is a paucity of validation studies to justify the use of these new equations on specific populations.

Rather than being dependent on genetic variability between ancestral groups, population changes in body proportions, and therefore stature, can be largely accredited to better living conditions, primarily improvements in nutrition, advancements in disease subjugation, technological developments resulting in a reduction in physical workload and a decrease in infant mortality and child labor [26]. Furthermore, according to Meadows Jantz and Jantz [27] in a study of historical skeletal collections, secular change has occurred allometrically in long bones in a United States population. This indicates that their proportions have changed across time with lower limb bones increasing in length and upper limb bones decreasing in length; therefore the current relationship to stature may be different from what is represented by older stature formulae. White males display a significantly higher rate of secular change than females, and lower limb bones tend to experience larger secular change than upper limb bones [27]. Additionally, it has recently been shown that in contemporary Euro-Americans, limb proportions have undergone considerable changes over the past 150 years due to the distinctive American environment, in particular, tibial length has been seen to increase while humeral length has decreased [28].

The femur provides the greatest contribution to living stature compared to any other single bone of the skeleton [10,29], with a femur:stature ratio of approximately 26.75% [30]. Therefore, it is not surprising that whilst Trotter and Gleser published sex-specific stature regression formulae for both upper and lower limb bones [5], the femoral equation has been reported as the most accurate for calculating stature (e.g. Refs. [10,31]).

Post mortem correction factors are used by researchers utilizing cadavers in stature studies due to discrepancies between cadaver stature and living stature. The Trotter and Gleser [5] recommendation of adding '2.5 cm' to the stature estimate has been a widely utilized correction factor, however a recent study by Cardoso et al. [32] investigated the relationship between cadaver and living stature, and identified an average difference of 4.3 cm, a greater difference than anticipated. The difference in statures has been ascribed to an expansion of intervertebral soft tissue, decrease of the spinal curvature, decompression of joints, and loss of muscle tonicity in cadavers [32,33]. Similarly living stature decreases with age due to the degeneration of vertebral bodies and intervertebral discs [34], prompting Trotter and Gleser [5] to recommend age correction factors for estimation of stature of individuals over 30 years of age, and Giles [35] and Galloway [36] to recommend sex-specific age correction factors for individuals over 45 years of age.

Currently no population specific standards exist for stature estimation using long bones in Australian casework, instead practitioners rely on outdated American regression formulae to identify human remains. Therefore, it is necessary to determine whether specific modifications to the existing sex-specific Trotter and Gleser [5] femoral equations are required for a modern Australian population. To overcome limited availability of physical contemporary skeletal collections in Australia, the use of computed tomography (CT) and 'virtual anthropology' provides an ideal tool to advance forensic anthropology research in Australia. Due to recent advances in technological capabilities, the utilization of multi-slice computed tomography (MSCT) and post mortem computed tomography (PMCT) alongside various software programs have enabled virtual reconstruction of human remains, leading to novel research directions and field applications in forensic anthropology [9,37–48]. Virtual anthropology utilizing MSCT has been demonstrated to have comparable accuracies to traditional osteometric methods [37,42,47].

This study will present an extensive examination of stature estimation using Bayesian models. Bayesian statistical modeling has become increasingly used in forensic anthropological research, with Konigsberg et al. [49] being one of the first to discuss the topic from a stature estimation perspective. This paper will firstly determine the measured difference between standing stature and supine stature in living individuals, then utilize this stature model to estimate standing stature from the supine stature of measured cadavers. Using Bayesian linear regression, model parameter estimates will be proposed for femoral measurements obtained using computed tomography (CT) three-dimensional (3D) models. An examination into the usefulness of age and sex when estimating stature will be conducted, and the proposed model will be compared to the Trotter and Gleser [5,6] parameters to examine the accuracy of stature estimation in an adult Queensland Caucasian population.

2. Materials and methods

2.1. Sample

The sample consisted of three-dimensional (3D) post mortem computed tomography (PMCT) scans of the left and right femora (scanned simultaneously) from 76 male (n = 51) and female (n = 25)